THE THERMAL BEHAVIOR OF PATCHING MATERIALS IN CONCRETE PAVEMENTS

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ABSTRACT

Patching works, one of the major concrete pavement maintenance works, are being widely used for their short traffic interruption time as a substitute for replacing with new materials after cutting out a part of the existing damaged pavement. There are many section repair materials used in road maintenance works. Most of them show good structural characteristics such as stiffness and strength. But, their field performances have not always been verified to be good as expected. This can be attributed to the ignorance of the compatibility between concrete and the patching materials. In fact, consideration of compatibility of the materials has often only been a concern for those with experience and awareness of the significance. Investigation into compatibility can be a useful tool for analyzing the cause of this malfunctioning and for recommending reliable guidelines. Furthermore, it is necessary to consider the relationship between bond stress and other compatibility characteristics such as the COTE and modulus of the patching materials. After investigating the COTE and modulus of patching materials recently used in the field, the effects of the COTE and modulus on the internal and interface stresses, are evaluated by numerical methods in this research. Through the results of this study, it is concluded that the bond strength needed in patching materials, depends on the COTE and modulus under certain temperatures and traffic loading conditions. The research results of this study may contribute to setting up rational guidelines for determining the proper patching materials for concrete pavements.

1. INTRODUCTION

There are many section repair materials used in road maintenance works. Most of them show good structural characteristics such as stiffness and strength. But, their field performances have not always been verified to be as good as expected. This can be attributed to ignorance of the compatibility between concrete and the patching materials. In fact, consideration of the compatibility of the materials has often only been a concern for those with experience and awareness of the significance.

The compatibility of patching materials is often expressed by characteristics such as elastic modulus and thermal coefficient of expansion (COTE) respectively and by their composite effects. Several researches were conducted to try to extract the guidelines for ensuring good field performance by presenting the compatibility criteria [1][4]. But most of them underestimated the effects of the compatibility on the mechanical characteristics. The difference in COTE between the pavement

concrete and the patching materials could influence the stress at the interface of the bond. Therefore, the criteria of the bonding strength should be estimated by considering the COTE differences. This can be also applied to the elastic modulus of the patching materials. In this paper, analysis is performed to verify the relationship between bond stress and the compatibility characteristics using analytical methods.

2. COMPATIBILITY OF PATCHING MATERIALS

To determine the patching materials to be used in the fields, the main factors that have been taken into consideration were a higher structural capacity such as tensile strength, compressive strength and bond strength more than any other alternatives. But lack of compatibility with the old pavement concrete has attributed to the poor performance of those materials. Some engineers became interested in the compatibility issue and focused on the need for a standard for selecting the proper materials.

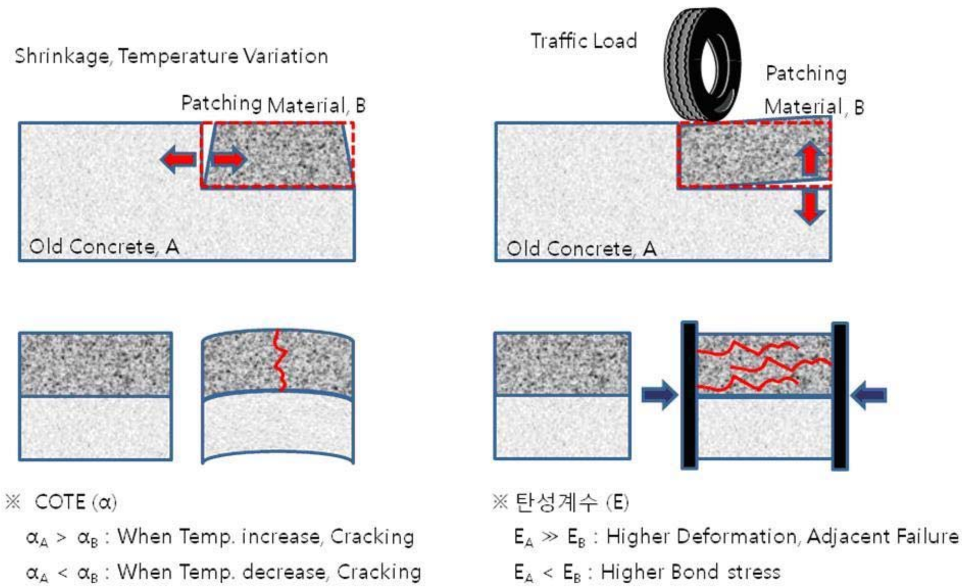

Figure 1. The effects of the COTE and modulus on the behavior of the patched area.

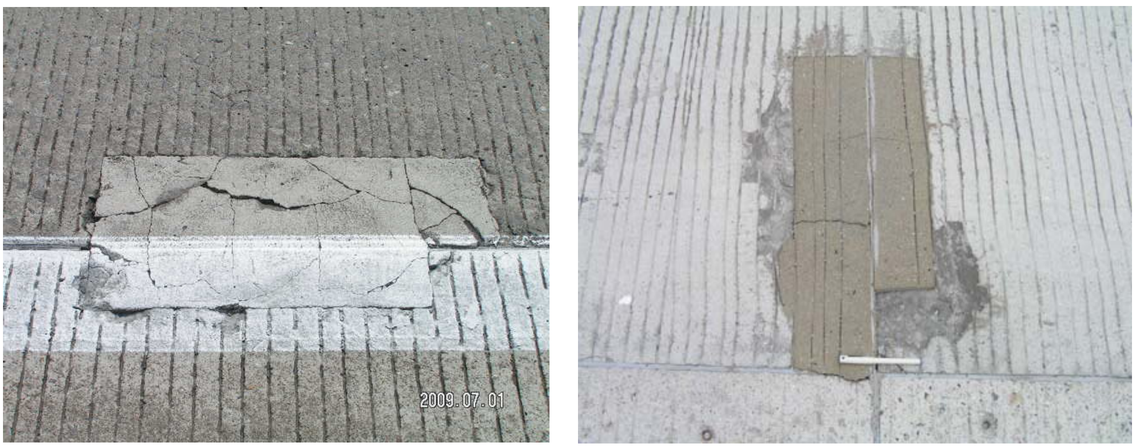

Figure 2. Premature failure of patched materials

The drying shrinkage, modulus of elasticity, COTE, and tensile creep, could be the elements of compatibility that need to be considered for patching. It is also a given that these elements depend upon the loading and environmental conditions of the location where the patching takes place. The requirements of patching materials can be classified into three categories, which are: structural characteristics, compatibility and durability. Among the compatibility elements, the COTE and the modulus of elasticity influence the performance of patching materials as graphically described in the Figure 1 [2].

3. THE COTE OF PATCHING MATERIALS IN A LABORATORY

For investigating the COTE variations of patching materials, tests on the COTE of some patching materials were conducted in accordance with the AASHTO TP-60 method. All the patching materials tested were concrete mixes containing coarse aggregate, fine aggregate and water binders.

The experimental results show the variances among the materials; most of them have a lower COTE than ordinary cement concrete with the exception of acrylate-based patching materials. Urethane-based materials shows the lowest value, which is 1/4 the COTE value of ordinary cement concrete. While a slightly higher value of COTE is shown in the acrylate-based materials, about half values are shown in epoxy-based and magnesium phosphate-based materials (Figure 3).

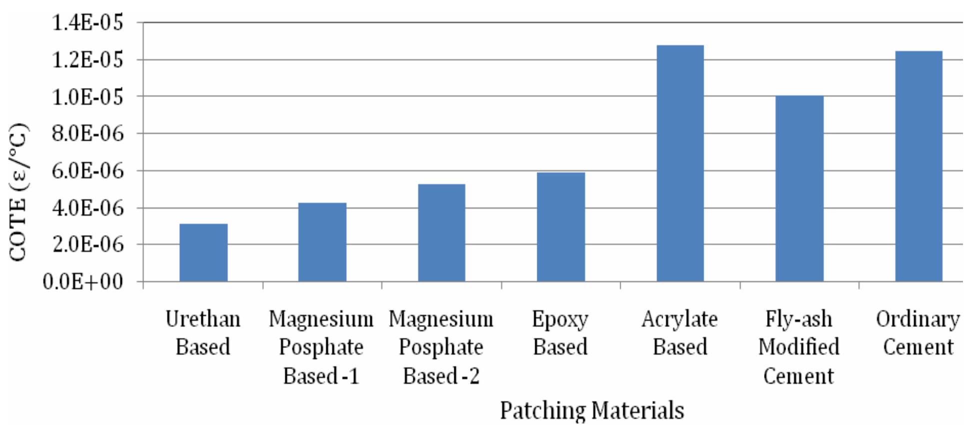

Figure 3. COTE test results of patching materials

4. THE ELASTIC MODULUS

The modulus test results show that the modulus of magnesium phosphate cement-based materials have similar value to ordinary cement concrete, but epoxy-based materials and acrylate-based materials have lower values. Notably, a considerable smaller modulus is shown in urethane-based materials compared with the other materials. The materials were selected as priorities as they are well known in fields. It is believed, using experience in the field, that the materials with lower than or similar to the modulus of old concrete are now prevailingly accepted in the field [6][7][8].

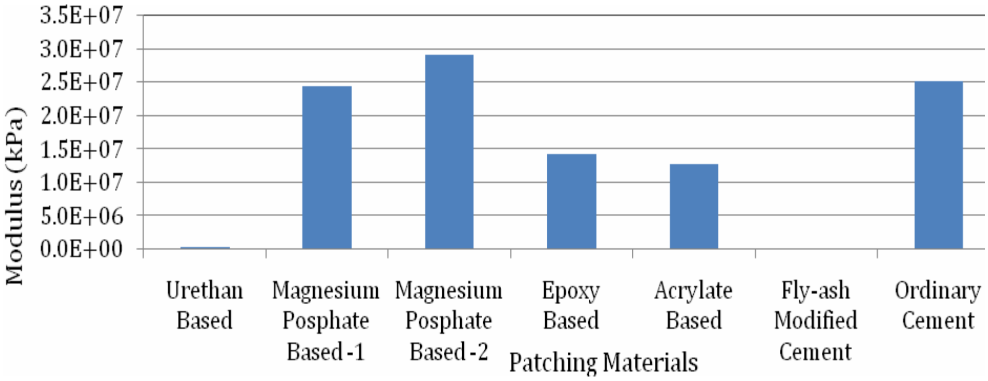

Figure 4. Modulus test results of patching materials (Fly-ash data was omitted)

5. THE BEHAVIOR OF PATCHING AREAS UNDER TEMPERATURE LOADS

5.1 ANALYSIS MODEL AND VARIABLES

Compatibility can be investigated by examining the behavior of patching areas under the temperature variations in depth using numerical methods. In this research, the finite element analysis was performed to examine the stresses and deformations of patched sections with various COTE and moduli under several combinations of temperature difference between upper and lower surface of concrete pavements.

3-D continuum solid elements with 8-nodes were used for modeling the patched concrete pavements (Figure 5). The model was a single symmetric quarter slab of 3.0m x 1.8m x 0.3m (length x width x depth) size, and the size of the patched area was 0.1m x 0.1m x 0.05m (length x width x depth). When the temperature changes per depth are loaded onto the slab using a variation of temperatures to the values of 30℃, 40℃, 50℃, the different COTE and moduli were input into the patching material characteristic logs as shown in Table 1 [9].

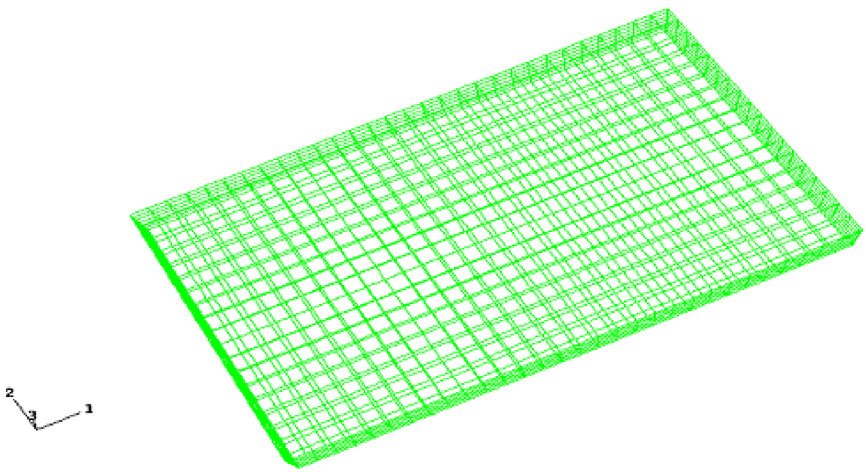

Figure 5. FE model for compatibility analysis.

Table 1. Load case of numerical analysis

Load Case	Case-1	Case-2	Case-3	Case-4	Case-5	Case-6	Case-7
Modulus (kPa)	1.0E+04	1.0E+05	1.0E+06	1.0E+07	2.0E+07	2.5E+07	3.0E+07
COTE (ε/℃)	1.0E-05	5.0E-05	1.0E-04	2.0E-04	4.0E-04	6.0E-04	
Old Concrete : Modulus=2.5E+07 kPa, COTE=1.0E-05 ε/℃							

5.2 ANALYSIS RESULTS

As the COTE of the patching materials increased, the internal stresses grew up rapidly as shown in Figures 6, 7, and 8. These figures represent the principal stress of the concrete slab under the temperature difference of 30℃. The stresses are also increase corresponding to the increasing value of the temperature difference. This kind of phenomenon is natural but it is more than expected. The Figures 9 and 10 show this trend with varying temperature difference of 40℃ and 50℃.

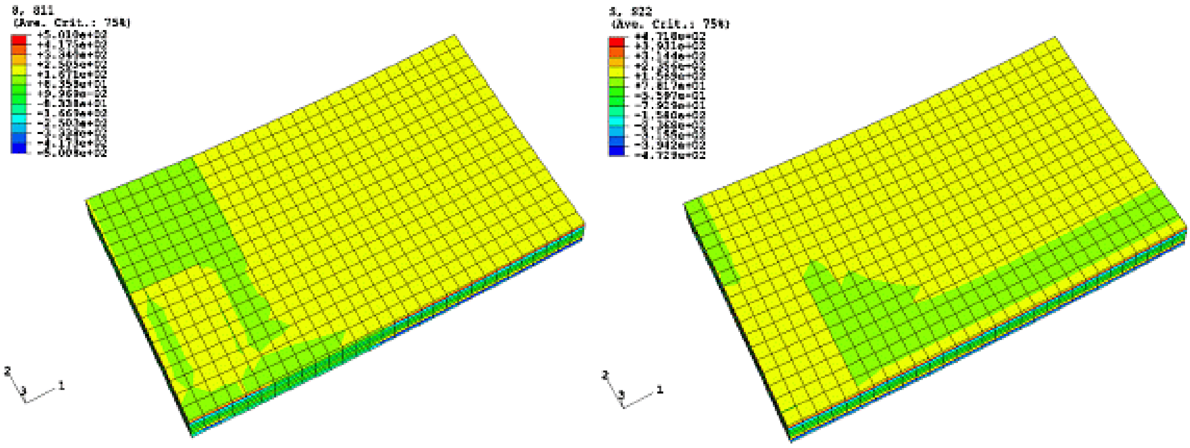

Figure 6. Principal stresses in slab under a temperature difference of 30℃ (Patching COTE : 1.0E-05 ε/℃)

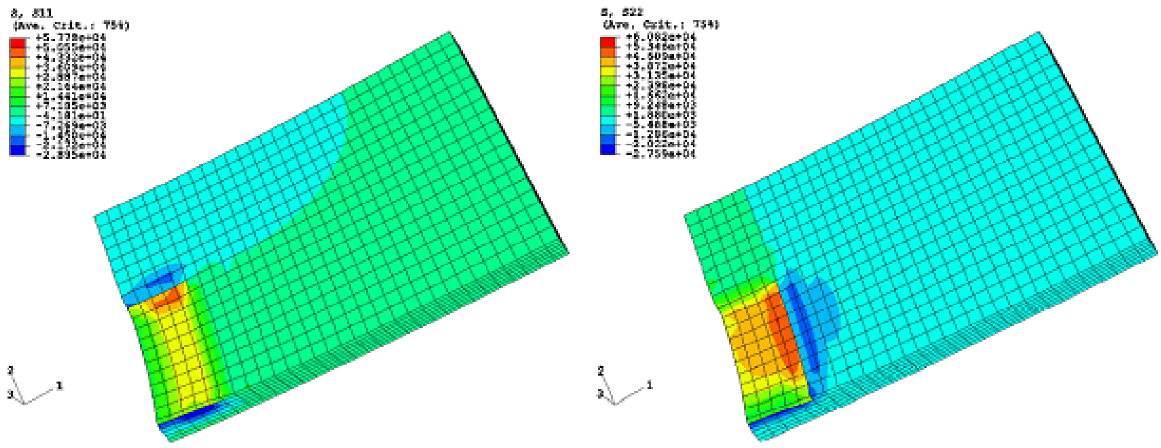

Figure 7. Principal stresses in slab under a temperature difference of 30°C (Patching COTE : 2.0E-04 ε/°C)

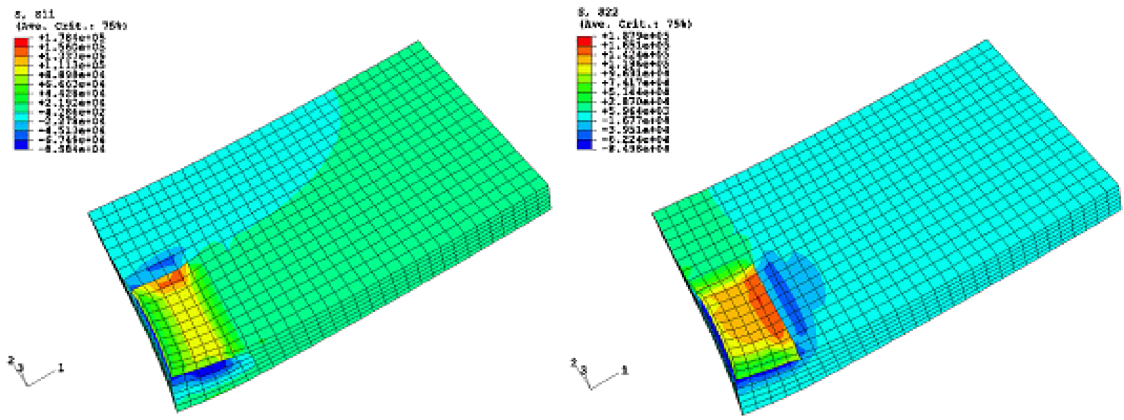

Figure 8. Principal stresses in slab under a temperature difference of 30°C (Patching COTE : 6.0E-04 ε/°C)

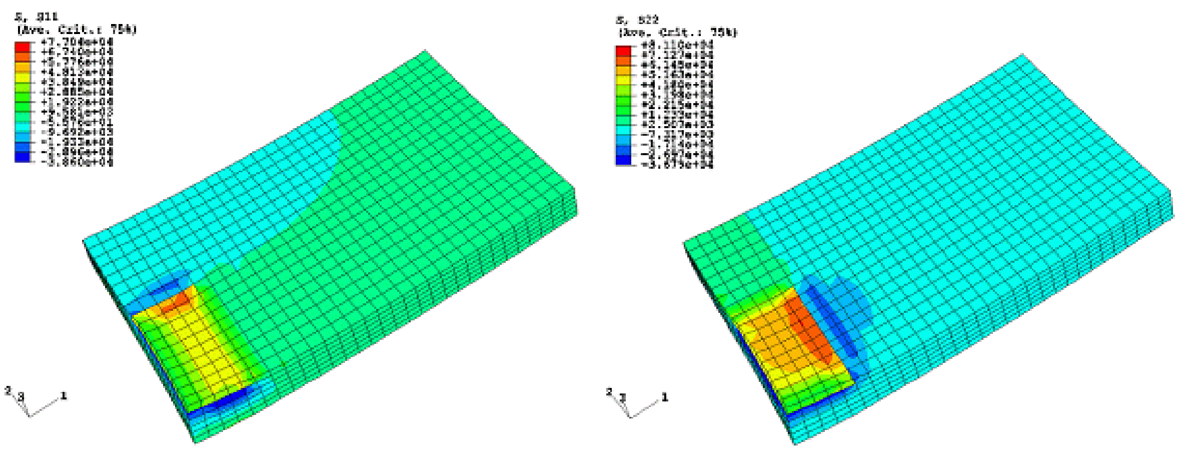

Figure 9. Principal stresses in slab under a temperature difference of 40°C (Patching COTE : 2.0E-04 ε/°C)

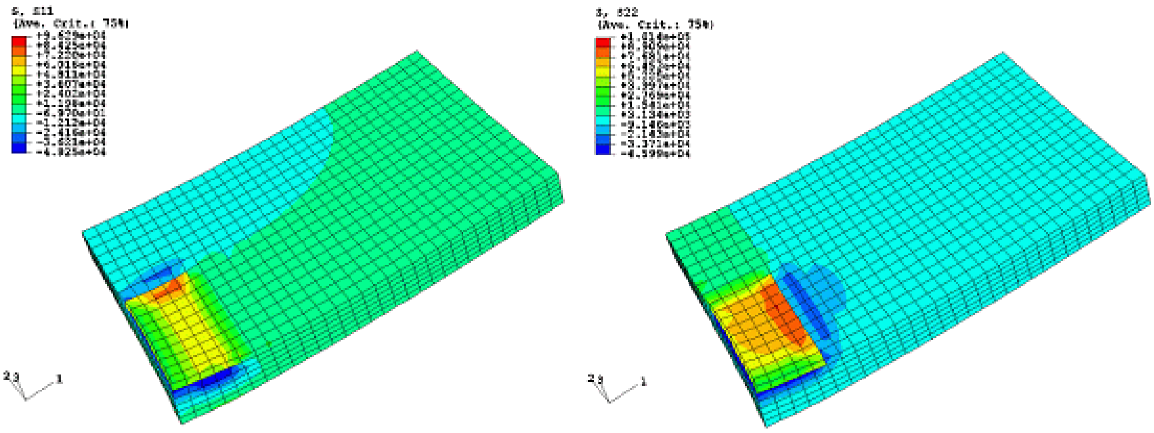

Figure 10. Principal stresses in slab under a temperature difference of 50°C (Patching COTE : 2.0E-04 ε/°C)

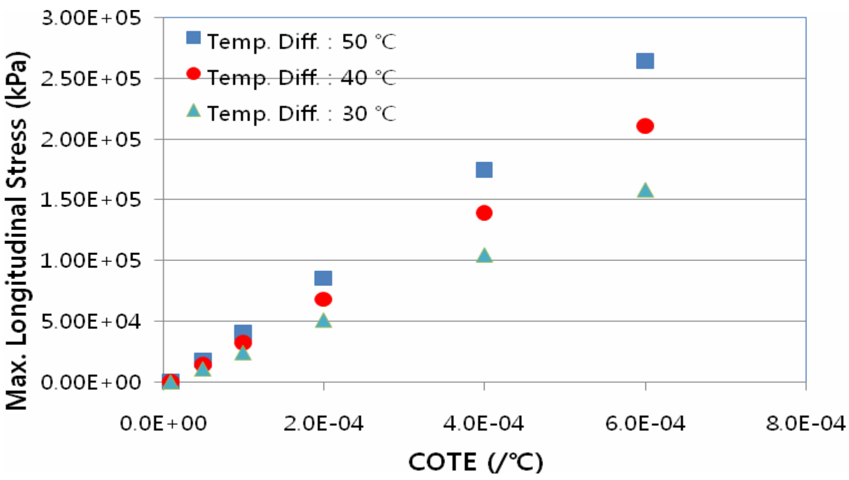

Figure 11. Maximum longitudinal stresses vs. COTE variation

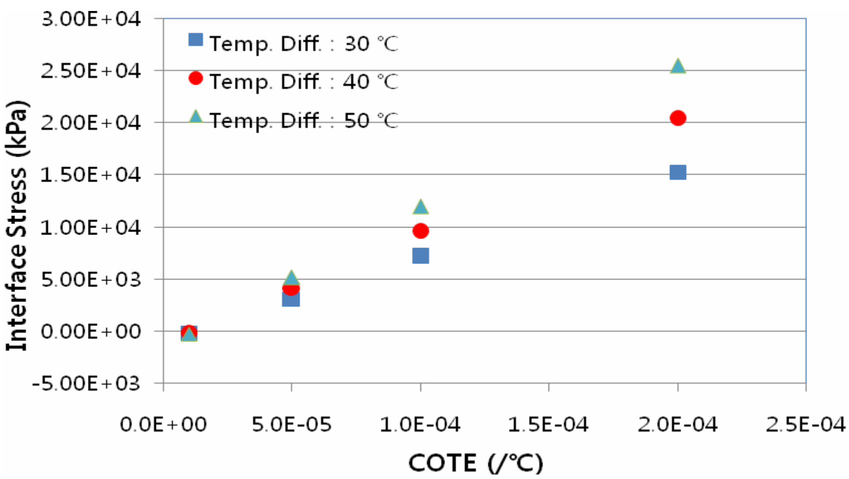

Figure 12. Vertical Stresses at the bonding interface vs. COTE variations

The internal and interface stresses rapidly rise according to the COTE value, and the higher temperature gradient is also a burden to the severity of the stress. This may excuse the patching materials with a higher strength than the old concrete in the pavement, but as shown in Figure 12, the accompanying interface stresses can also induce the real problems of bond failure. In other words, patching materials with a higher COTE should guarantee higher bonding characteristics.

Similar results on the effects from the modulus on the stress are derived from the analysis output. Figures 13 and 14 show that higher stress occurs in the patching materials with a higher modulus of elasticity. This is a certain evidence of the common understanding that the lower modulus can be good to fair performance in the field.

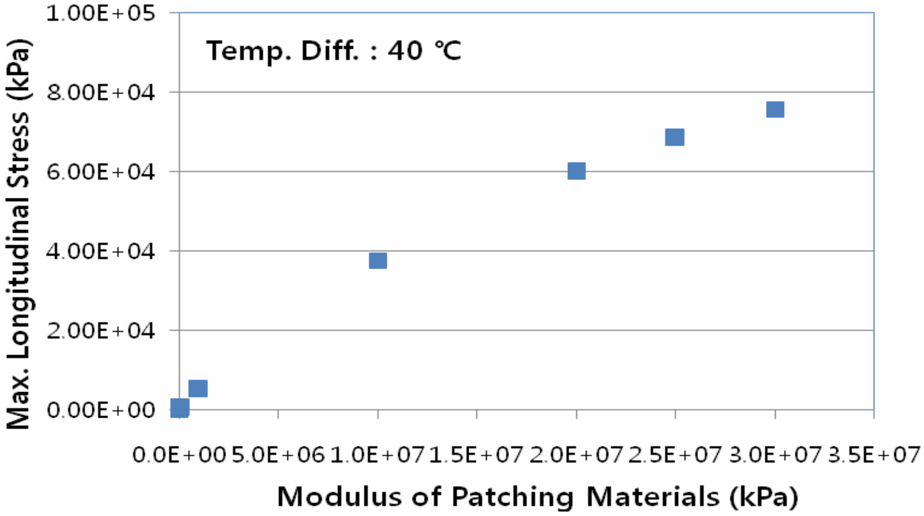

Figure 13. Maximum longitudinal stresses vs. modulus variations

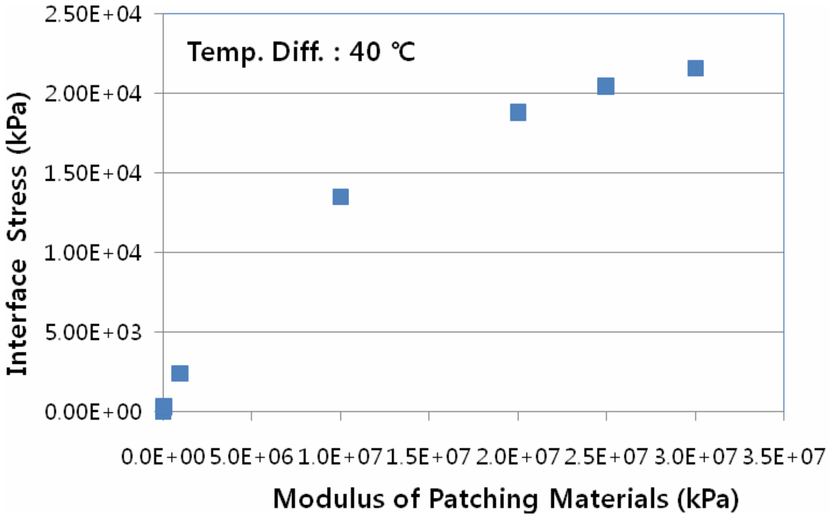

Figure 14. Vertical stresses at the bonding interface vs. modulus variation

The results described in the previous section, seemingly show that the lower COTE and the lower modulus of the patching materials cause lower stress, but normally materials with a lower COTE have a stiffer modulus than other materials. That is, both values have reciprocal

characteristics. Because of this, the research conducted in the TTI(Texas Transportation Institute, USA) and others recommend the use of a multiple value($E\alpha$) of two as a selecting guide for patching materials [4].

In addition to this concept, bond stress should be considered as a related property, because COTE and modulus do influence the bond stress, which critically determines the performance of the patching materials. Expensive and unnecessary surface treatment on all types of materials may occur if this is not taken into.

6. CONCLUSION

In the past, patching materials have been selected only considering their structural capacity, such as compressive strength, tensile strength and bond strength. But even those materials with a higher level of stiffness, and some more sophisticated materials have not shown good performances. The investigation of compatibility can be a useful tool for analyzing the cause of this malfunctioning and for recommending reliable guidelines. Furthermore, it is necessary to consider the relationship between bond stress and other compatibility characteristics such as the COTE and modulus of the patching materials.

After investigating the COTE and modulus of the patching materials used recently in the fields, the effects of the COTE and modulus on the internal and interface stresses, are evaluated by numerical methods in this research. Through the results of this study, it is concluded that the bond strength needed in the patching materials, depends on the COTE and modulus under certain temperatures and traffic loading conditions.

The research results of this study may contribute to setting up some rational guidelines for determining the proper patching materials of concrete pavements. Further research is expected in this area, which will considers the combining effects of compatibility characteristics such as shrinkage, the COTE, and the modulus on performance factors like bond strength.

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